



CAT661

High Frequency 100mA CMOS Charge Pump, Inverter/Doubler

FEATURES

- Converts V_+ to V_- or V_+ to $2V_+$
- Low output resistance, 10Ω max.
- High power efficiency
- Selectable charge pump frequency of 25kHz or 135kHz; optimize capacitor size.
- Low quiescent current
- Pin-compatible to MAX660, LTC660 with higher frequency operation
- Available in 8-pin SOIC, DIP and 0.8mm thin 4x4mm TDFN packages
- Lead-free, halogen-free package option

APPLICATIONS

- Negative voltage generator
- Voltage doubler
- Voltage splitter
- Low EMI power source
- GaAs FET biasing
- Lithium battery power supply
- Instrumentation
- LCD contrast bias
- Cellular phones, pagers

DESCRIPTION

The CAT661 is a charge-pump voltage converter. It can invert a positive input voltage to a negative output. Only two external capacitors are needed. With a guaranteed 100mA output current capability, the CAT661 can replace a switching regulator and its inductor. Lower EMI is achieved due to the absence of an inductor.

In addition, the CAT661 can double a voltage supplied from a battery or power supply. Inputs from 2.5V to 5.5V will yield a doubled, 5V to 11V output.

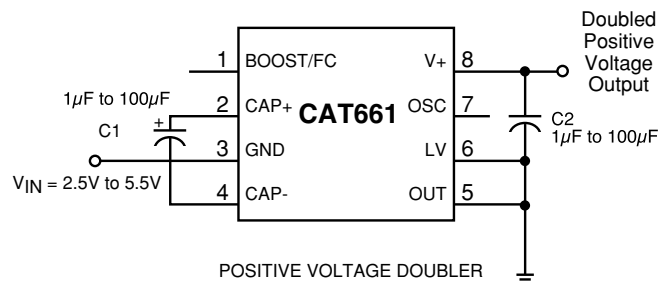
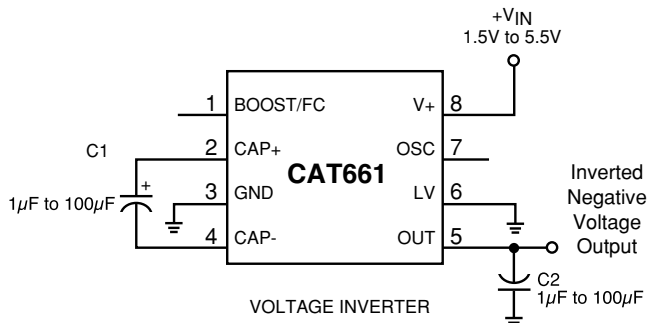
A Frequency Control pin (BOOST/FC) is provided to select either a high (typically 135kHz) or low (25kHz) internal oscillator frequency, thus allowing quiescent current vs. capacitor size trade-offs to be made. The 135kHz frequency is selected when the FC pin is

connected to V_+ . The operating frequency can also be adjusted with an external capacitor at the OSC pin or by driving OSC with an external clock.

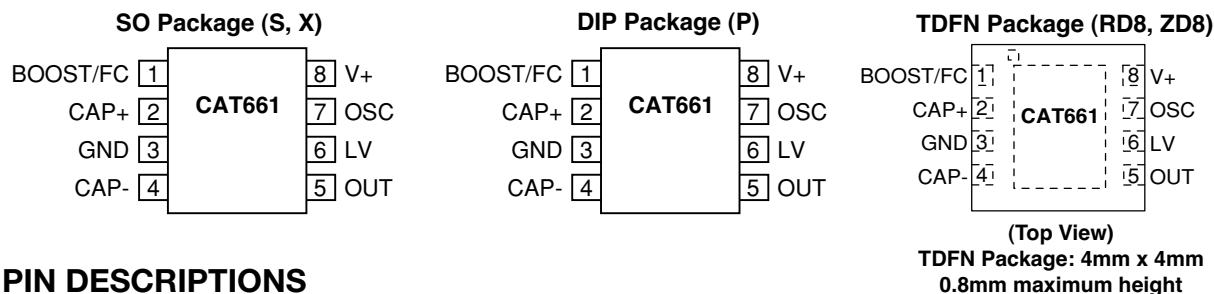
Both 8-pin DIP and SO packages are available. The TDFN package 4x4mm footprint features a 0.8mm maximum height. For die availability, contact Catalyst Semiconductor marketing.

The CAT661 can replace the MAX660 and the LTC660 in applications where higher oscillator frequency and smaller capacitors are needed. In addition, the CAT661 is pin compatible with the 7660/1044, offering an easy upgrade for applications with 100mA loads.

TYPICAL APPLICATION



PIN CONFIGURATION



PIN DESCRIPTIONS

| Pin Number | Name | Circuit Configuration | |
|------------|----------|--|---|
| | | Inverter | Doubler |
| 1 | Boost/FC | Frequency Control for the internal oscillator. With an external oscillator BOOST/FC has no effect. | |
| | | Boost/FC | Oscillator Frequency |
| | | Open | 25kHz typical, 10kHz minimum |
| | | V+ | 135kHz typical, 80kHz minimum |
| 2 | CAP+ | Charge Pump Capacitor. Positive terminal. | Same as inverter. |
| 3 | GND | Power Supply Ground. | Power supply. Positive voltage input. |
| 4 | CAP- | Charge pump capacitor. Negative terminal. | Same as inverter. |
| 5 | OUT | Output for negative voltage. | Power supply ground. |
| 6 | LV | Low-Voltage selection pin. When the input voltage is less than 3V, connect LV to GND. For input voltages above 3V, LV may be connected to GND or left open. If OSC is driven externally, connect LV to GND. | LV must be tied to OUT for all input voltages. |
| 7 | OSC | Oscillator control input. An external capacitor can be connected to lower the oscillator frequency. An external oscillator can drive OSC and set the chip operating frequency. The charge-pump frequency is one-half the frequency at OSC. | Same as inverter. Do not overdrive OSC in doubling mode. Standard logic levels will not be suitable. See the applications section for additional information. |
| 8 | V+ | Power supply. Positive voltage input. | Positive voltage output. |

ORDERING INFORMATION

| Part Number | Package | Temperature Range |
|----------------|--------------------------------------|-------------------|
| CAT661EPA | 8 lead Plastic DIP | -40°C to 85°C |
| CAT661ESA | 8-lead SO | -40°C to 85°C |
| CAT661ESA-TE13 | 8-lead SO, Tape & Reel | -40°C to 85°C |
| CAT661EVA | 8-lead SO (Lead-free, Halogen-free) | -40°C to 85°C |
| CAT661EVA-TE13 | 8-lead SO (Lead-free, Halogen-free) | -40°C to 85°C |
| CAT661ERD8 | 8-pad TDFN | -40°C to 85°C |
| CAT661EZD8 | 8-pad TDFN (Lead-free, Halogen-free) | -40°C to 85°C |

ABSOLUTE MAXIMUM RATINGS

V₊ to GND 6V

Input Voltage (Pins 1, 6 and 7) .. -0.3V to (V₊ + 0.3V)

BOOST/FC and OSC Input Voltage The least negative of (Out - 0.3V) or (V₊ - 6V) to (V₊ + 0.3V)

Output Short-circuit Duration to GND 1 sec.

(OUT may be shorted to GND for 1 sec without damage but shorting OUT to V₊ should be avoided.)

Continuous Power Dissipation (T_A = 70°C)

Plastic DIP 730mW

SO 500mW

TDFN 1W

Storage Temperature -65°C to 160°C

Lead Soldering Temperature (10 sec) 300°C

ESD Rating-Human Body Model 2000V

Note: T_A = Ambient Temperature

These are stress ratings only and functional operation is not implied. Exposure to absolute maximum ratings for prolonged time periods may affect device reliability. All voltages are with respect to ground.

Operating Ambient Temperature Ranges

CAT661E -40°C to 85°C

ELECTRICAL CHARACTERISTICS

V₊ = 5V, C1 = C2 = 100μF, Boost/FC = Open, C_{OSC} = 0pF, and Test Circuit is Figure 1 unless otherwise noted. Temperature is T_A = T_{AMIN} to T_{AMAX} unless otherwise noted.

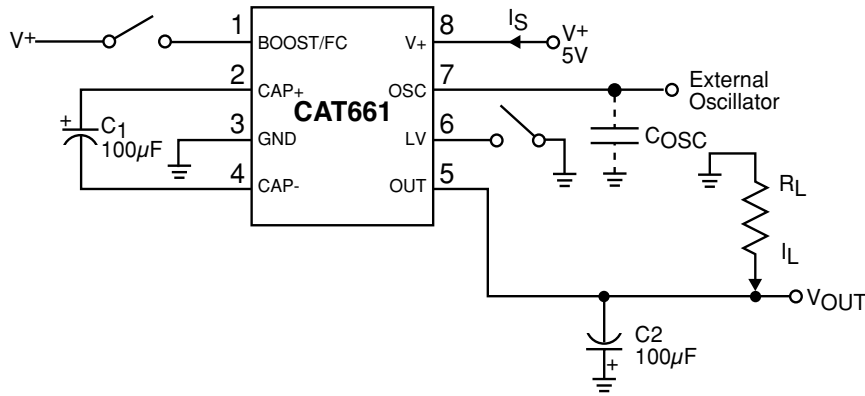
| Parameter | Symbol | Conditions | Min. | Typ | Max. | Units |
|----------------------------------|------------------|---|------|-----------|------|-------|
| Supply Voltage | VS | Inverter: LV = Open. R _L = 1kΩ | 3.0 | | 5.5 | V |
| | | Inverter: LV = GND. R _L = 1kΩ | 1.5 | | 5.5 | |
| | | Doubler: LV = OUT. R _L = 1kΩ | 2.5 | | 5.5 | |
| Supply Current | IS | BOOST/FC = open, LV = Open | | 0.2 | 0.5 | mA |
| | | BOOST/FC = V ₊ , LV = Open | | 1 | 3 | |
| Output Current | I _{OUT} | OUT is more negative than -4V | 100 | | | mA |
| Output Resistance | RO | C1 = C2 = 10μF, BOOST/FC = V ₊ (C1, C2 ESR ≤ 0.5Ω) | | 3.5 | 10 | Ω |
| | | C1 = C2 = 100μF (Note 2) | | 3.5 | 10 | |
| Oscillator Frequency (Note 3) | FO _{SC} | BOOST/FC = Open | 10 | 25 | | kHz |
| | | BOOST/FC = V ₊ | 80 | 135 | | |
| OSC Input Current | I _{OSC} | BOOST/FC = Open BOOST/FC = V ₊ | | ±2 ±10 | | μA |
| Power Efficiency | PE | R _L = 1kΩ connected between V ₊ and OUT, T _A = 25°C (Doubler) | 96 | 98 | | % |
| | | R _L = 500Ω connected between GND and OUT, T _A = 25°C (Inverter) | 92 | 96 | | |
| | | I _L = 100mA to GND, T _A = 25°C (Inverter) | | 88 | | |
| Voltage Conversion Efficiency | VEFF | No load, T _A = 25°C | 99 | 99.9 | | % |

1. In Figure 1, test circuit electrolytic capacitors C1 and C2 are 100μF and have 0.2Ω maximum ESR. Higher ESR levels may reduce efficiency and output voltage.

2. The output resistance is a combination of the internal switch resistance and the external capacitor ESR. For maximum voltage and efficiency keep external capacitor ESR under 0.2Ω.

3. FO_{SC} is tested with C_{OSC} = 100pF to minimize test fixture loading. The test is correlated back to C_{OSC}=0pF to simulate the capacitance at OSC when the device is inserted into a test socket without an external C_{OSC}.

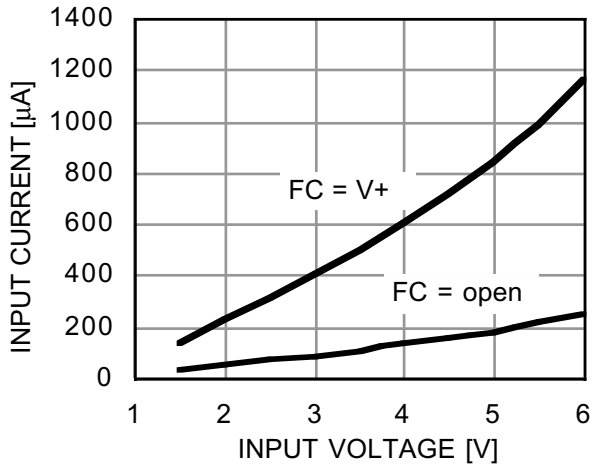
Figure 1. Test Circuit Voltage Inverter



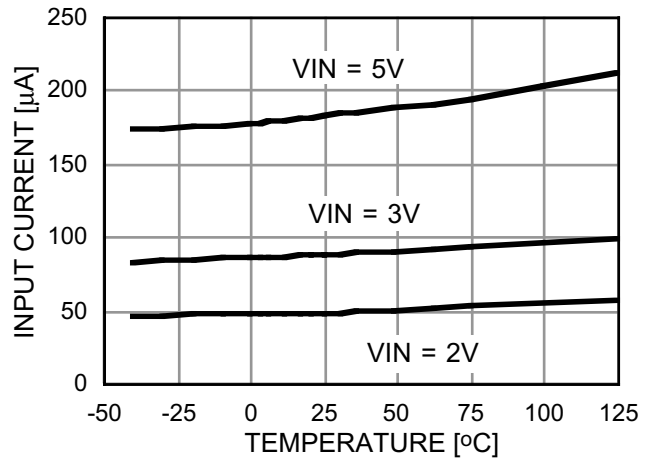
TYPICAL OPERATING CHARACTERISTICS

Typical characteristic curves are generated using the circuit in Figure 1. Inverter test conditions are: $V_+ = 5V$, $LV = GND$, $BOOST/FC = Open$ and $T_A = 25^\circ C$ unless otherwise indicated. Note that the charge-pump frequency is one-half the oscillator frequency.

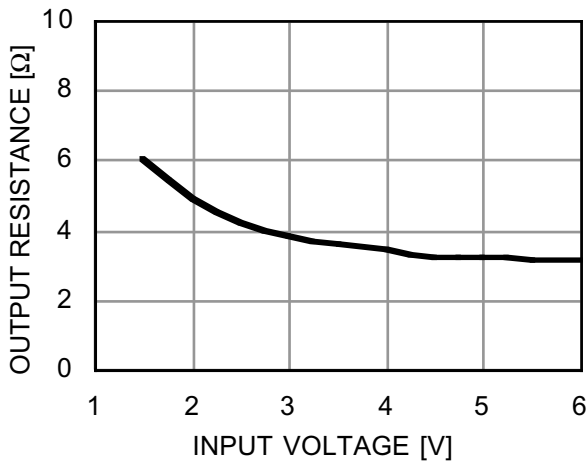
Supply Current vs. Input Voltage



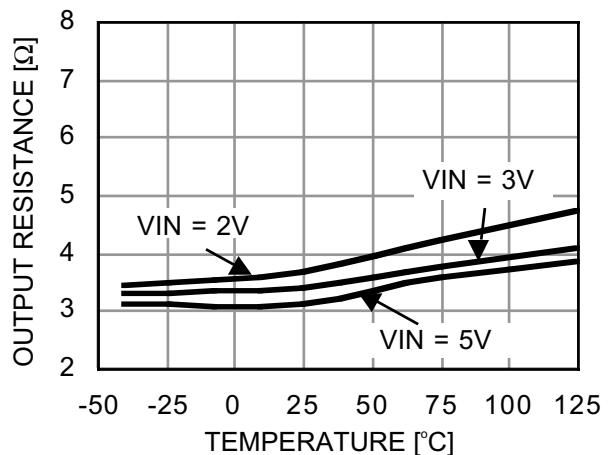
Supply Current vs. Temperature (No Load)



Output Resistance vs. Input Voltage

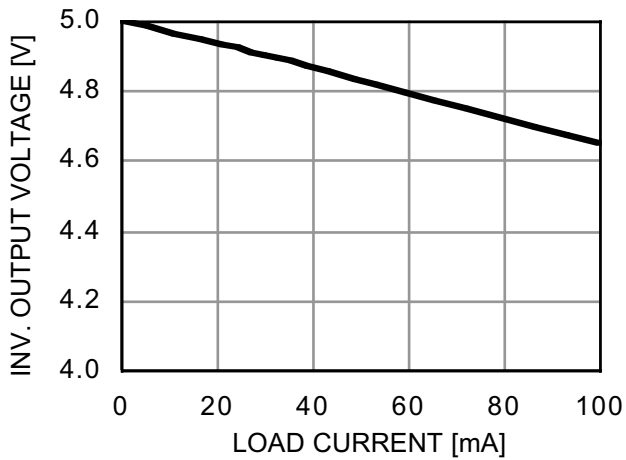


Output Resistance vs. Temperature (50Ω load)

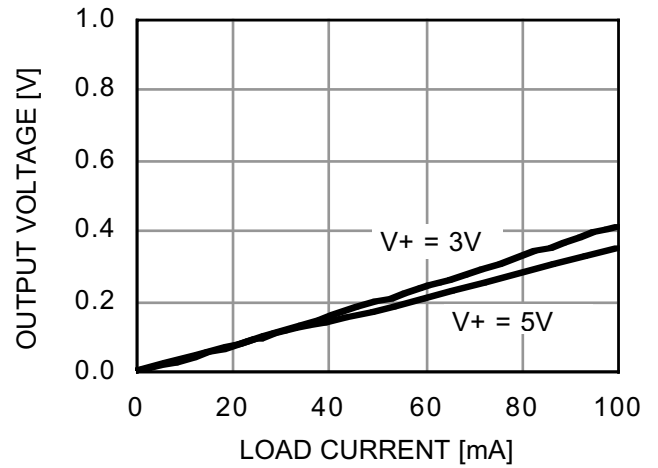


TYPICAL OPERATING CHARACTERISTICS

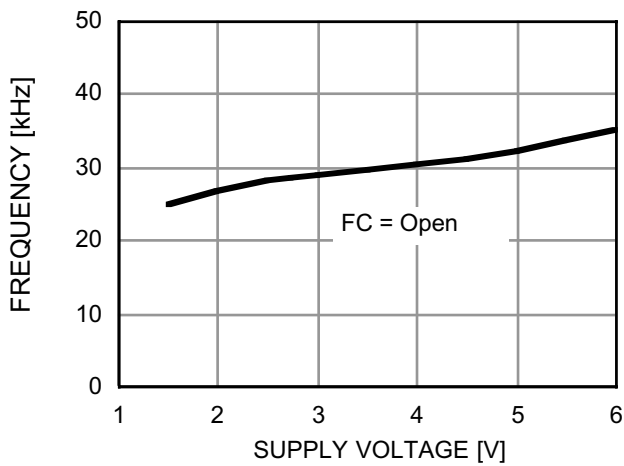
Inverted Output voltage vs. Load, $V_+ = 5V$



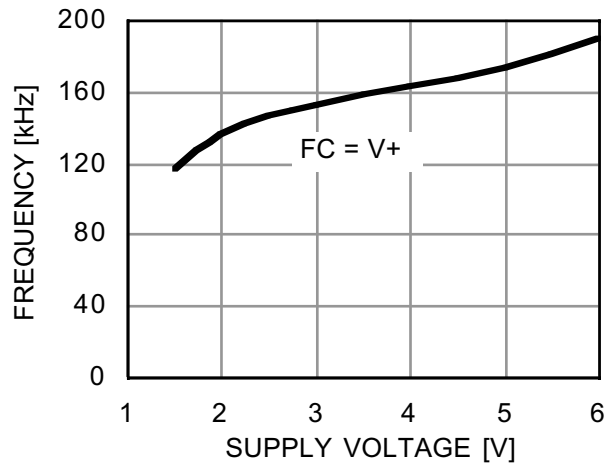
Output Voltage Drop vs. Load Current



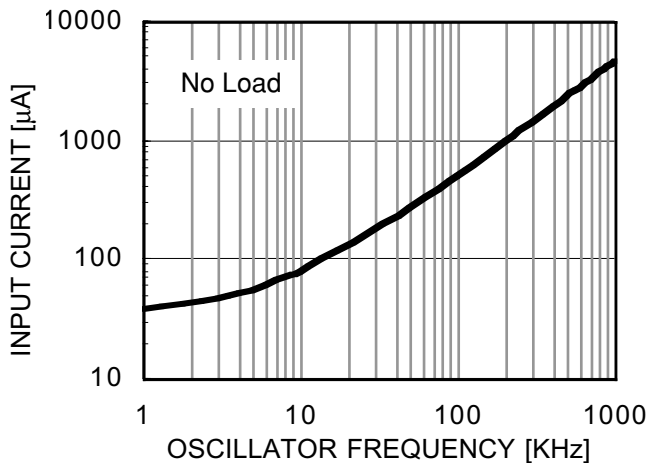
Oscillator Frequency vs. Supply Voltage



Oscillator Frequency vs. Supply Voltage



Supply Current vs. Oscillator Frequency



Efficiency vs. Load Current

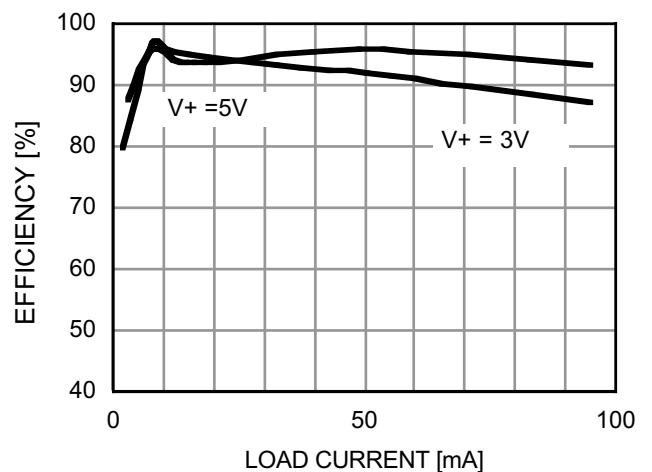
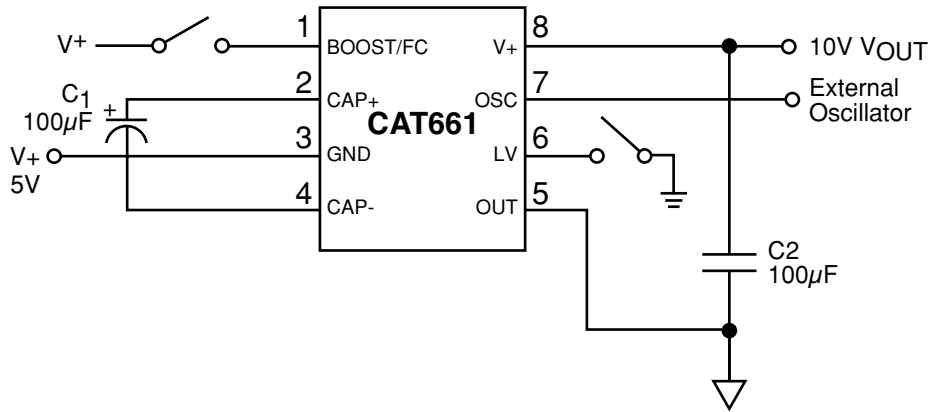


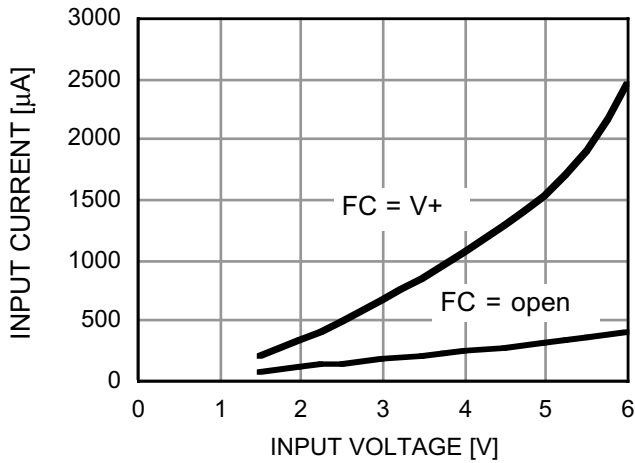
Figure 2. Test Circuit Voltage Doubler



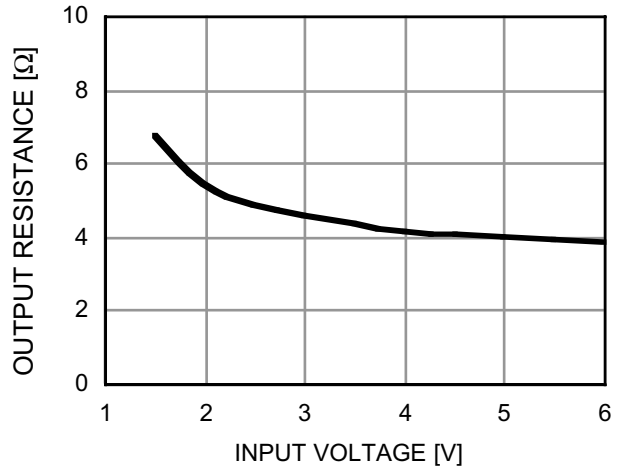
TYPICAL OPERATING CHARACTERISTICS

Typical characteristic curves are generated using the circuit in Figure 2. Doubler test conditions are: V+ 5V, LV = GND, BOOST/FC = Open and T_A = 25°C unless otherwise indicated.

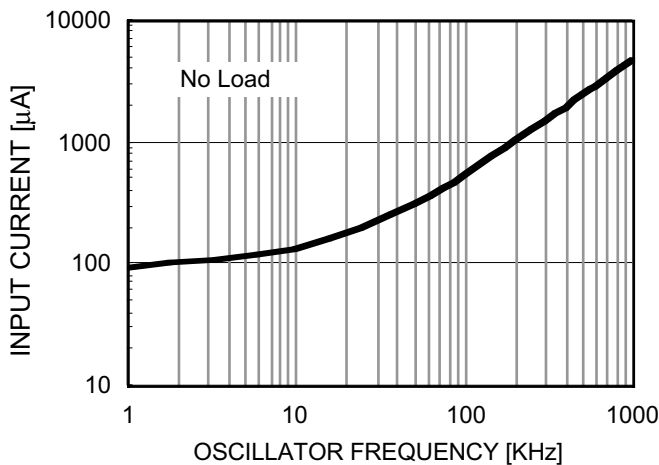
Supply Current vs. Input Voltage (No Load)



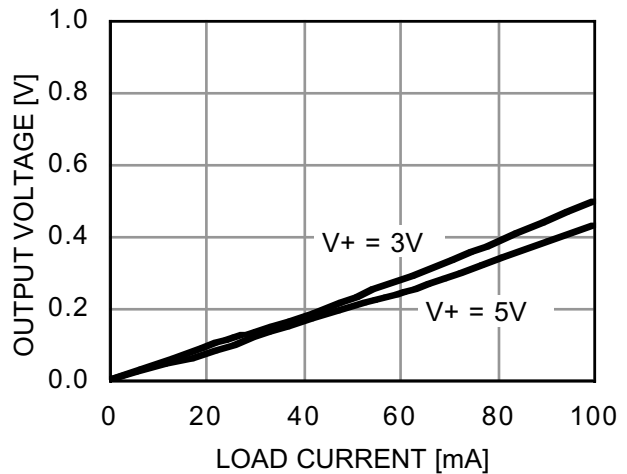
Output Resistance vs. Input Voltage



Supply Current vs. Oscillator Frequency



Output Voltage Drop vs. Load Current



APPLICATION INFORMATION

Circuit Description and Operating Theory

The CAT661 switches capacitors to invert or double an input voltage.

Figure 3 shows a simple switch capacitor circuit. In position 1 capacitor C1 is charged to voltage V1. The total charge on C1 is $Q1 = C1V1$. When the switch moves to position 2, the input capacitor C1 is discharged to voltage V2. After discharge, the charge on C1 is $Q2 = C1V2$.

The charge transferred is:

$$\Delta Q = Q1 - Q2 = C1 \times (V1 - V2)$$

If the switch is cycled "F" times per second, the current (charge transfer per unit time) is:

$$I = F \times \Delta Q = F \times C1 (V1 - V2)$$

Rearranging in terms of impedance:

$$I = \frac{(V1-V2)}{(1/FC1)} = \frac{V1-V2}{REQ}$$

The $1/FC1$ term can be modeled as an equivalent impedance REQ . A simple equivalent circuit is shown in figure 4. This circuit does not include the switch resistance nor does it include output voltage ripple. It does allow one to understand the switch-capacitor topology and make prudent engineering tradeoffs.

For example, power conversion efficiency is set by the output impedance, which consists of REQ and switch resistance. As switching frequency is decreased, REQ , the $1/FC1$ term, will dominate the output impedance, causing higher voltage losses and decreased efficiency. As the frequency is increased quiescent current increases. At high frequency this current becomes significant and the power efficiency degrades.

The oscillator is designed to operate where voltage losses are a minimum. With external $150\mu\text{F}$ capacitors, the internal switch resistances and the Equivalent Series Resistance (ESR) of the external capacitors determine the effective output impedance.

A block diagram of the CAT661 is shown in figure 5.

Figure 3. Switched-Capacitor Building Block

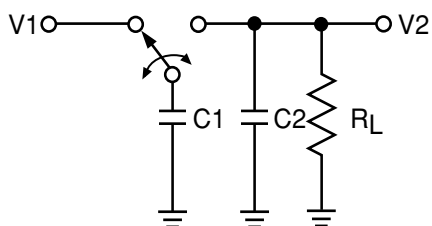
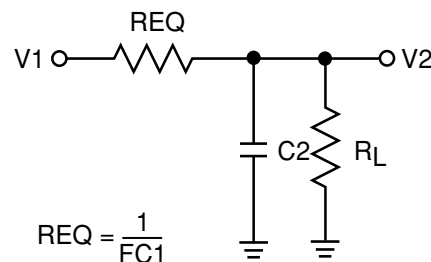


Figure 4. Switched-Capacitor Equivalent Circuit



OSCILLATOR FREQUENCY CONTROL

The switching frequency can be raised, lowered or driven from an external source. Figure 6 shows a functional diagram of the oscillator circuit.

The CAT661 oscillator has four control modes:

| BOOST/FC Pin Connection | OSC Pin Connection | Nominal Oscillator Frequency |
|-------------------------|--------------------|------------------------------|
| Open | Open | 25kHz |
| BOOST/FC= V+ | Open | 135kHz |
| Open or BOOST/FC= V+ | External Capacitor | — |
| Open | External Clock | Frequency of external clock |

If BOOST/FC and OSC are left floating (Open), the nominal oscillator frequency is 25kHz. The pump frequency is one-half the oscillator frequency.

By connecting the BOOST/FC pin to V+, the charge and discharge currents are increased, and the frequency is increased by approximately 6 times. Increasing the frequency will decrease the output impedance and ripple currents. This can be an advantage at high load currents. Increasing the frequency raises quiescent current but allows smaller capacitance values for C1 and C2.

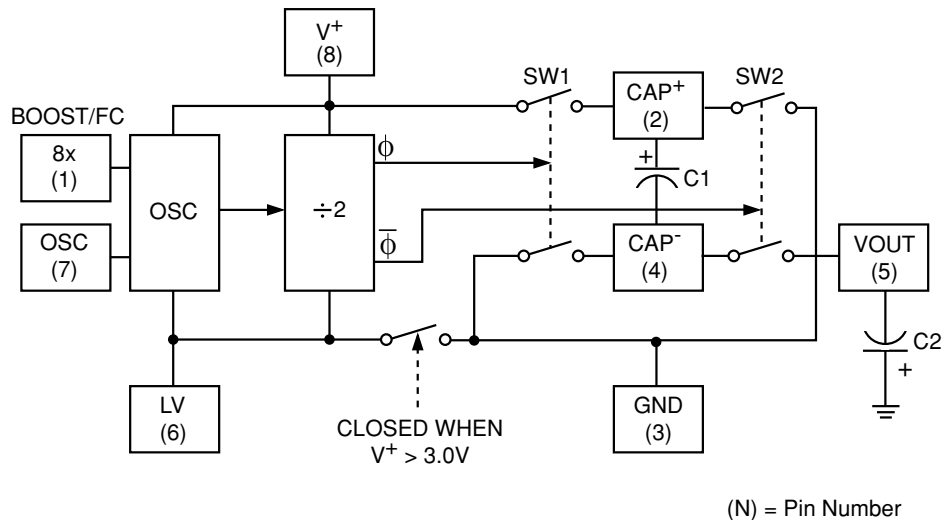
If pin 7, OSC, is loaded with an external capacitor the frequency is lowered. By using the BOOST/FC pin and

an external capacitor at OSC, the operating frequency can be set.

Note that the frequency appearing at CAP+ or CAP- is one-half that of the oscillator.

Driving the CAT661 from an external frequency source can be easily achieved by driving Pin 7 and leaving the BOOST pin open, as shown in figure 6. The output current from Pin 7 is small, typically 1µA to 8µA, so a CMOS can drive the OSC pin. For 5V applications, a TTL logic gate can be used if an external 100kΩ pull-up resistor is used as shown in figure 7.

Figure 5. CAT661 Block Diagram



CAPACITOR SELECTION

Low ESR capacitors are necessary to minimize voltage losses, especially at high load currents. The exact values of C1 and C2 are not critical but low ESR capacitors are necessary.

The ESR of capacitor C1, the pump capacitor, can have a pronounced effect on the output. C1 currents are approximately twice the output current and losses occur on both the charge and discharge cycle. The ESR effects are thus multiplied by four. A 0.5Ω ESR for C1 will have the same effect as a 2Ω increase in CAT661 output impedance.

Output voltage ripple is determined by the value of C2 and the load current. C2 is charged and discharged at a current roughly equal to the load current. The internal switching frequency is one-half the oscillator frequency.

$$VRIPPLE = I_{OUT} / (F_{OSC} \times C2) + I_{OUT} \times ESR_{C2}$$

For example, with a 25kHz oscillator frequency (12.5kHz switching frequency), a 150μF C2 capacitor with an ESR of 0.2Ω and a 100mA load peak-to-peak the ripple voltage is 45mV.

VRIPPLE vs. FOSC

| VRIPPLE (mV) | I _{OUT} (mA) | F _{OSC} (kHz) | C2 (μF) | C2 ESR (Ω) |
|--------------|-----------------------|------------------------|---------|------------|
| 45 | 100 | 25 | 150 | 0.2 |
| 25 | 100 | 135 | 150 | 0.2 |

Figure 6. Oscillator

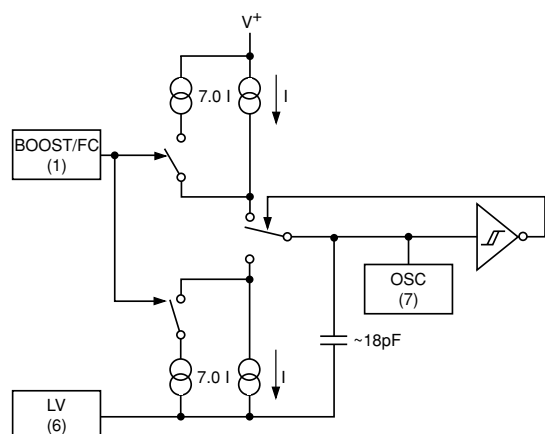
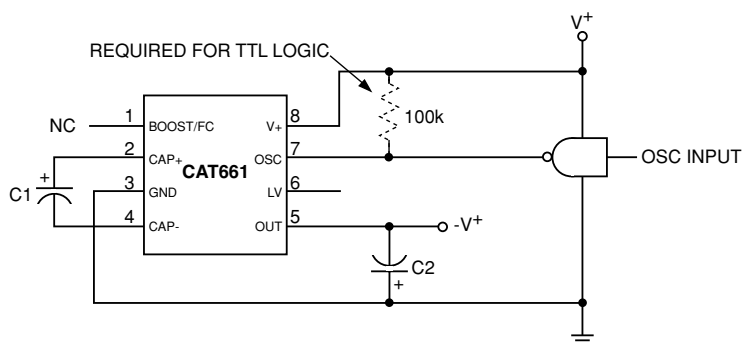


Figure 7. External Clocking



CAPACITOR SUPPLIERS

The following manufacturers supply low-ESR capacitors:

| Manufacturer | Capacitor Type | Phone | WEB | Email | Comments |
|----------------|----------------|--------------|---------------------|--------------------|----------|
| AVX/Kyocera | TPS/TPS3 | 843-448-9411 | www.avxcorp.com | avx@avxcorp.com | Tantalum |
| Vishay/Sprague | 595 | 402-563-6866 | www.vishay.com | — | Aluminum |
| Sanyo | MV-AX, UGX | 619-661-6835 | www.sanyo.com | Svcsales@sanyo.com | Aluminum |
| Nichicon | F55 | 847-843-7500 | www.nichicon-us.com | — | Tantalum |
| | HC/HD | | | | Aluminum |

Capacitor manufacturers continually introduce new series and offer different package styles. It is recommended

that before a design is finalized capacitor manufacturers should be surveyed for their latest product offerings.

CONTROLLING LOSS IN CAT661 APPLICATIONS

There are three primary sources of voltage loss:

1. Output resistance
 $V_{LOSS} = I_{LOAD} \times R_{OUT}$, where R_{OUT} is the CAT661 output resistance and I_{LOAD} is the load current.
2. Charge pump (C1) capacitor ESR:
 $V_{LOSSC1} \approx 4 \times ESR_{C1} \times I_{LOAD}$, where $ESRC1$ is the ESR of capacitor C1.
3. Output or reservoir (C2) capacitor ESR:
 $V_{LOSSC2} = ESR_{C2} \times I_{LOAD}$, where $ESRC2$ is the ESR of capacitor C2.

The effective output impedance of a CAT661 circuit is approximately:

$$R_{circuit} \approx R_{out\ 661} + (4 \times ESR_{C1}) + ESR_{C2}$$

VOLTAGE INVERSION POSITIVE-TO-NEGATIVE

The CAT661 easily provides a negative supply voltage from a positive supply in the system. Figure 8 shows a typical circuit. The LV pin may be left floating for positive input voltages at or above 3.3V.

Increasing the value of C2 and/or decreasing its ESR will reduce noise and ripple.

TYPICAL APPLICATIONS

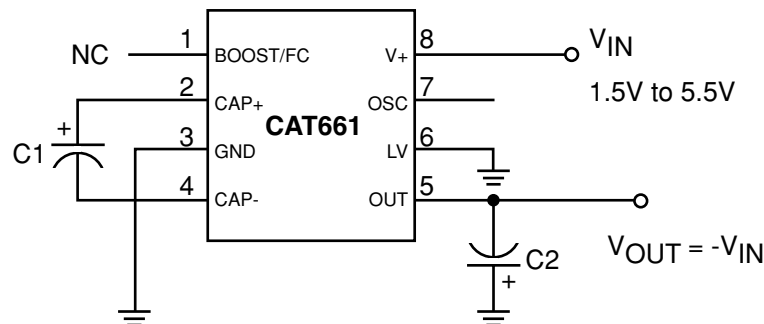


Figure 8: Voltage Inverter

POSITIVE VOLTAGE DOUBLER

The voltage doubler circuit shown in figure 9 gives $V_{OUT} = 2 \times V_{IN}$ for input voltages from 2.5V to 5.5V.

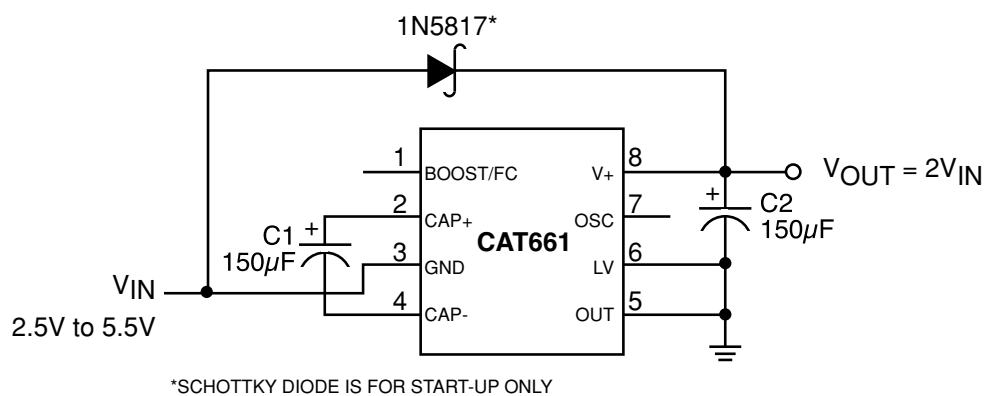


Figure 9: Voltage Doubler

PRECISION VOLTAGE DIVIDER

A precision voltage divider is shown in figure 10. With load currents under 100nA, the voltage at pin 2 will be within 0.002% of $V^+/2$.

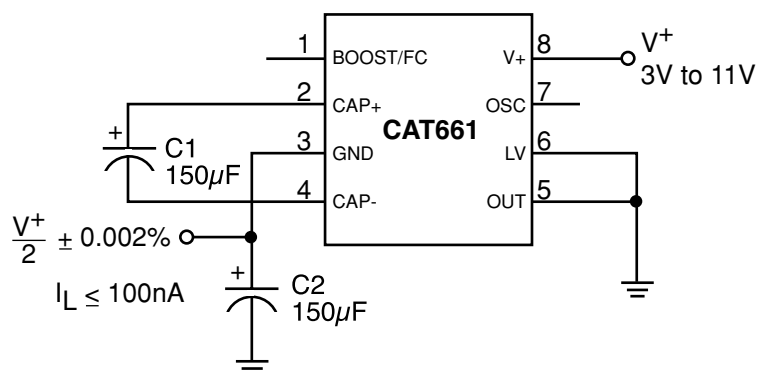


Figure 10: Precision Voltage Divider (Load $\leq 100\text{nA}$)

BATTERY VOLTAGE SPLITTER

Positive and negative voltages that track each other can be obtained from a battery. Figure 11 shows how a 9V battery can provide symmetrical positive and negative voltages equal to one-half the battery voltage.

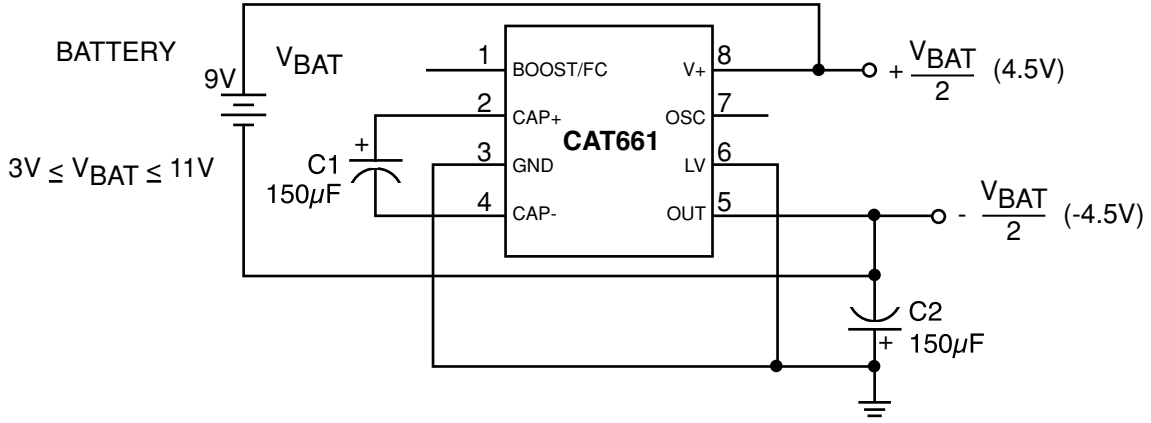


Figure 11: Battery Splitter

CASCADE OPERATION FOR HIGHER NEGATIVE VOLTAGES

The CAT661 can be cascaded as shown in figure 12 to generate more negative voltage levels. The output resistance is approximately the sum of the individual CAT661 output resistance.

$V_{OUT} = -N \times V_{IN}$, where N represents the number of cascaded devices.

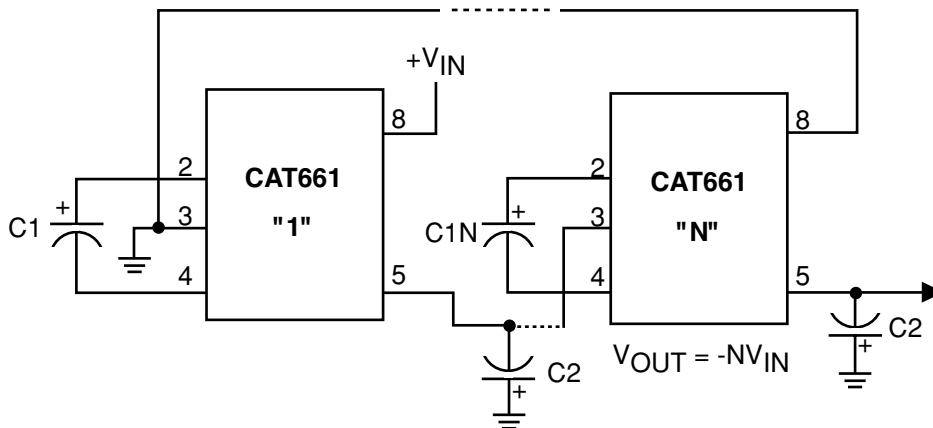


Figure 12: Cascading to Increase Output Voltage

PARALLEL OPERATION

Paralleling CAT661 devices will lower output resistance. As shown in figure 13, each device requires its own pump capacitor, C2, but the output reservoir capacitor is shared with all devices. The value of C2 should be increased by a factor of N, where N is the number of devices.

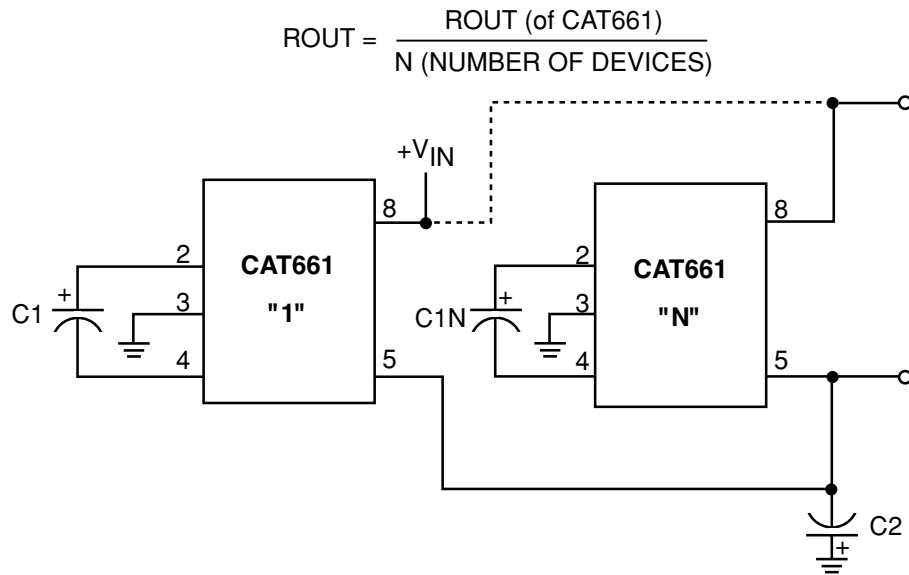
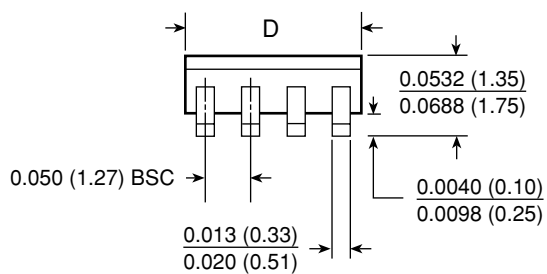
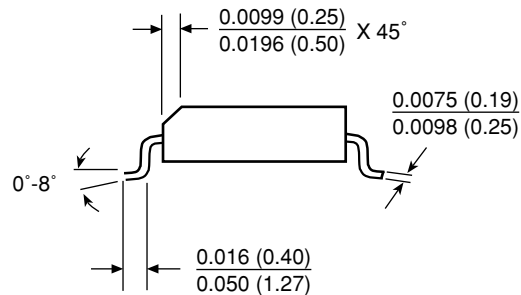
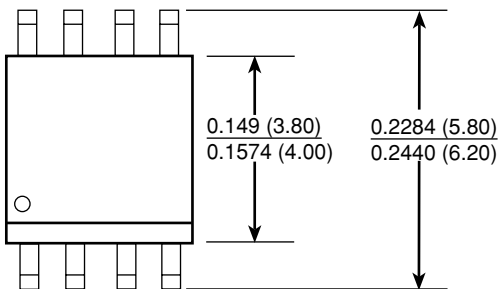


Figure 13: Reduce Output Resistance by Paralleling Devices

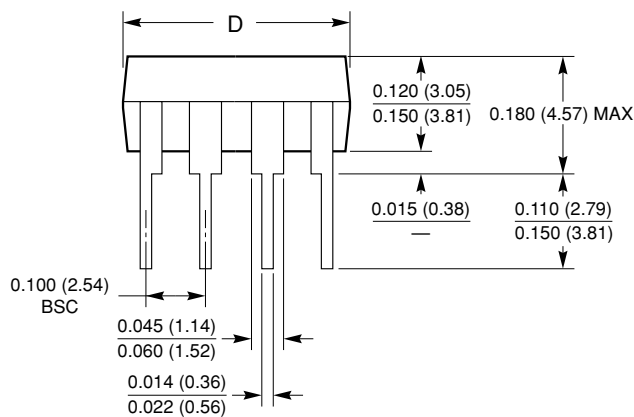
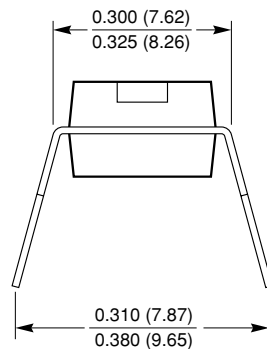
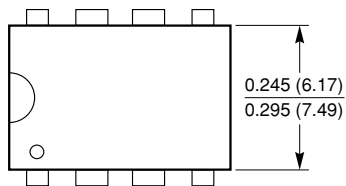
PACKAGE MECHANICAL DRAWINGS

8-LEAD 150 WIDE SOIC (S, X)



| Dimension D | | |
|-------------|--------------|--------------|
| Pkg | Min | Max |
| 8L | 0.1890(4.80) | 0.1968(5.00) |

8-LEAD 300 MIL WIDE PLASTIC DIP (P)



| Dimension D | | |
|-------------|--------------|---------------|
| Pkg | Min | Max |
| 8L | 0.355 (9.02) | 0.400 (10.16) |

Notes:

1. Complies with JEDEC Publication 95 MS001 dimensions; however, some of the dimensions may be more stringent.
2. All linear dimensions are in inches and parenthetically in millimeters.

REVISION HISTORY

| Date | Rev. | Reason |
|------------|------|--|
| 10/15/03 | G | Updated Description - eliminated Commercial temperature range |
| 10/27/04 | H | Minor changes throughout data sheet |
| 1/20/2005 | I | Changed ordering information for CAT661EXA to CAT661EVA Changed ordering information for CAT661EXA-TE13 to CAT661EVA-TE13 |
| 04/22/2005 | J | Removed Preliminary Information from data sheet header |

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